EAIntegrated Seismic Processing Challenges in Karstified Terrain of Papua New Guinea Fold Belt*

Subhash Chandra[1], Michael Szczepaniak[1], and Patrick Haltmeier[1]

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[1]Oil Search Limited, Port Moresby, Papua New Guinea (subhash.chandra@oilsearch.com)

Introduction

Seismic exploration in the PNG Highlands (Figure 1) poses many challenges both in the acquisition and in the processing of the data. The seismic method is limited by both operational and geophysical technical constraints. The remote field, rugose terrain, weather and local stakeholder issues are some of the numerous factors that make operations both difficult and, at times, dangerous. Technical issues are caused by complex subsurface structure, karstified limestone, velocity inversion, and extreme topography.

These issues result in the cost of acquiring seismic data in excess of $250,000 per kilometre. This high acquisition cost makes 3D data uneconomic. Therefore, highly complex 3D structures have to be interpreted from 2D seismic image only. The seismic data acquired in the PNG Highlands is amongst the most difficult in the world to process. A primary reason for this is that the signal-to-noise ratio of the acquired data is very low, making many established processing techniques difficult to implement. In order to process the data, it has been necessary to rethink many conventional approaches and come up with unique and novel techniques. The quality of the final processed data, although still poor when compared to other areas, has been continuously improved over many years.

Seismic Acquisition

Many different 2D production parameters have been used to acquire data in the Highlands. Until the early 1990's recording equipment limitations imposed restrictions on the number of channels, fold and maximum offset that could be recorded. In later years, as equipment improved, these limitations were largely addressed.

Despite the advances in acquisition technology, the quality of the recorded data, although better than earlier years, remains poor in comparison to other areas of the world. The main cause of this is the karst limestone that covers much of the highlands and, in some places, is more than a kilometre thick. This karstified layer, combined with the extreme topography, both attenuates and scatters the seismic energy at both the shot and receiver ends of the travel path resulting in data that is extremely noisy with a very low signal-to-noise ratio. A typical shot record (Figure 2) is dominated by noise with little reflection energy apparent.

Many experimental surveys have been performed since the late 1980's using different parameters, techniques and hardware to investigate how to acquire data that results in better images of the subsurface. Examples of what has been tested include:

1) Different source depths, intervals, charge sizes and hole patterns.
2) Different receiver intervals, arrays and depths.
3) Single geophones cemented into place.
4) Swath line shooting.
5) Crooked line acquisition on the top of limestone ridges.
6) Extremely long offset data subsequently processed using specialised algorithms.
7) Passive seismic surveys.
8) 3C data using MEM's sensors.
9) Cable free node-based recording.

Other techniques, such as 3D surveys or cross-spread arrays, that may be expected to give an improved subsurface image are so costly using currently technology that they cannot be economically justified even for experimental purposes.

Results from these tests have shown that there is, as yet, no "magic bullet" that gives a big lift in data quality. However, by incorporating the results from the tests, the recorded data quality has been improved in incremental steps. An example of these improvements on the final subsurface image is shown in Figure 3 that compares data of two vintages shot over the same region, before any improvements and data after all the incremental improvements.

Seismic Data Processing

Processing is an area where significant improvements in data quality have been realised. Using an integrated methodology that uses all the available data such as surface attributes (lithology, dip and azimuth, fault locations), well attributes (dips, azimuths, etc.) and strontium dating for base limestone prediction, the Processing Geophysicist, working iteratively with the Interpreter and Structural Geologist, has been able to produce data that is much improved from that which was previously possible. In addition, advances in processing algorithms have recently made possible increased use of prestack imaging techniques that were previously not successful due to the low signal-to-noise ratio of the data.

A typical poststack imaging processing sequence used over many years on highlands data is shown in Figure 4. It utilises poststack migration as the key imaging tool due to the much-improved signal-to-noise ratio of the stack data. This sequence produces subsurface images that are of reasonable quality in many areas of the highlands despite its simplistic flow and reliance on the flat layer assumptions of conventional NMO and Stack. The 2005 seismic section shown in Figure 3 is an example of data with this sequence applied.

Recent advances in noise attenuation and imaging algorithms have allowed prestack imaging to be more successfully used on highlands data. Many conventional strategies rely on coarse grids to increase the fold and output signal quality at the expense of horizontal resolution. Similarly, stacking velocity analysis often requires a combination of several CMP gathers in order to obtain meaningful stacking velocities. This method, however, fails to improve the stacking velocity analysis in case of strong dip. The same limitations due to dip are found for flexible binning techniques that may be used in order to close some data gaps. In many situations, coarse processing grids are not adequate for successful pre-processing techniques.

In the imaging of sparse data, however, significant dip enhancement and noise suppression can be achieved, using the alternative strategy of Common-Reflection-Surface (CRS) imaging which was firstly presented by Muller (1998, 1999). This technique is successfully applied to Highland data to enhance the imaging.

Another problem in the Highland area is a near-surface velocity problem due to complex geology, severe lateral velocity in the near surface area and rough topography. To solve near-surface velocity problems, several techniques have been proposed. One of them is First-arrival travel-time tomography (Nolet, 1987; Lutter et al., 1990; Aldridge and Oldenburg, 1992; Ammon and Vidale, 1993; Nemeth et al., 1997; Zhang and Tok-soz, 1998, and many others).

Figure 5 shows the example of conventional processing sequence, and Figure 6 shows the result after using the conventional processing sequence.

Figure 7 shows the example of CRS processing flow, and Figure 8 shows the result after using the CRS processing sequence.

Figure 9 shows the example of First arrival travel-time (FAT) Tomography processing flow, and Figure 10 shows the result using First arrival travel-time (FAT) Tomography PSTM processing flow.

Conclusions

- PNG Highland is very complex area in terms of geology and cost of acquiring seismic is very high because of accessibility and the resources in PNG Highland areas.

- Acquiring good quality seismic is another challenge because of complex subsurface geology. Source energy is highly attenuated because of the existing carbonate layer and incoming signals are contaminated by different types of noises due to water seepage, highly dense forest, and lateral variation in the elevations, etc.

- Imaging through seismic processing is another challenge because of the limitations of acquired good quality seismic data.

- To reduce noise in acquired seismic data, different methodologies and latest techniques have been experimented with the Highland area which helped to parameterise future seismic projects in this area.

- Oil Search adopted different seismic processing techniques for better subsurface imaging which has improved the seismic image. Imaging by seismic processing requires another level of experiment to get the best resolution for further interpretation purposes.

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Figure 1. Papua New Guinea Highlands: extreme terrain.

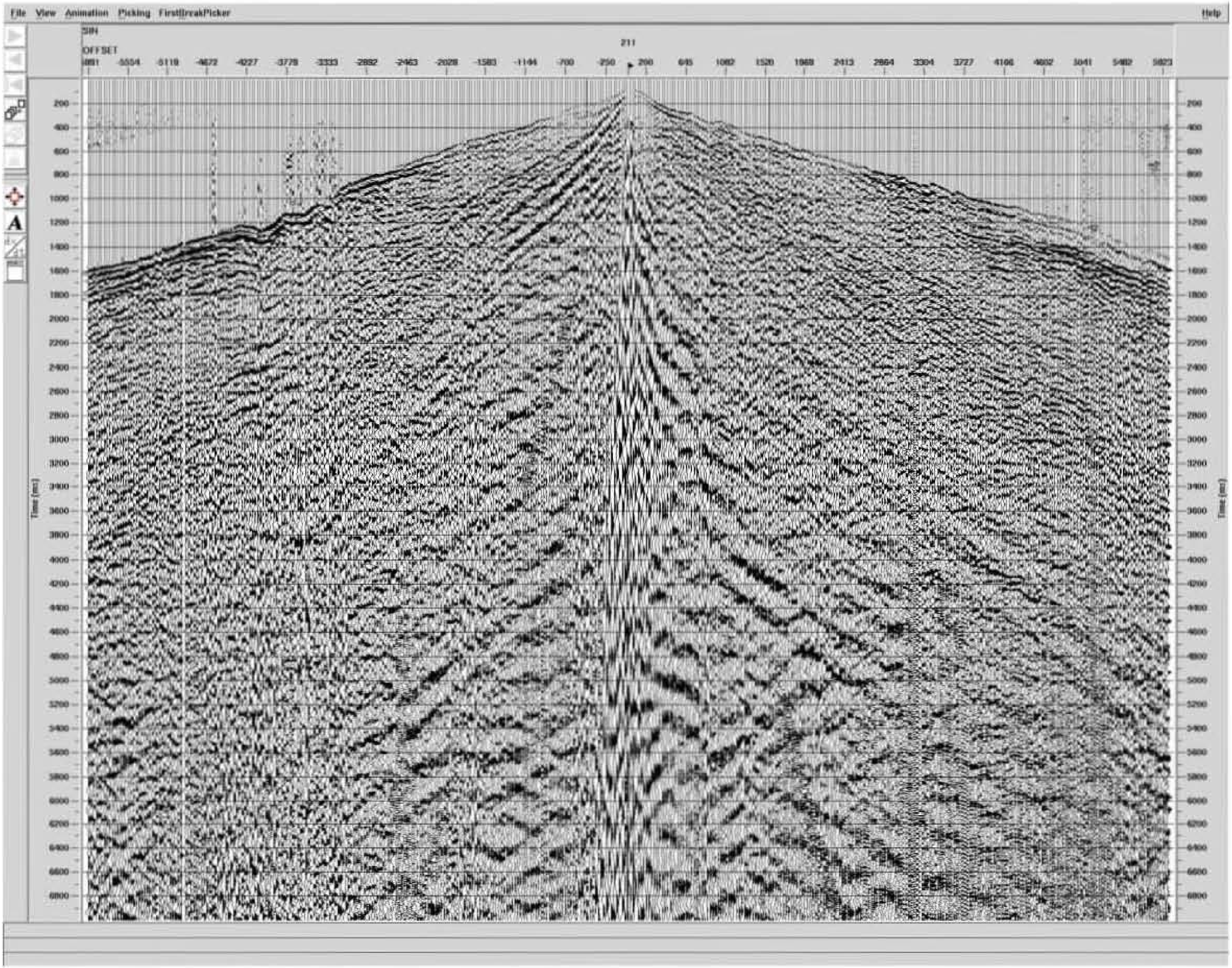
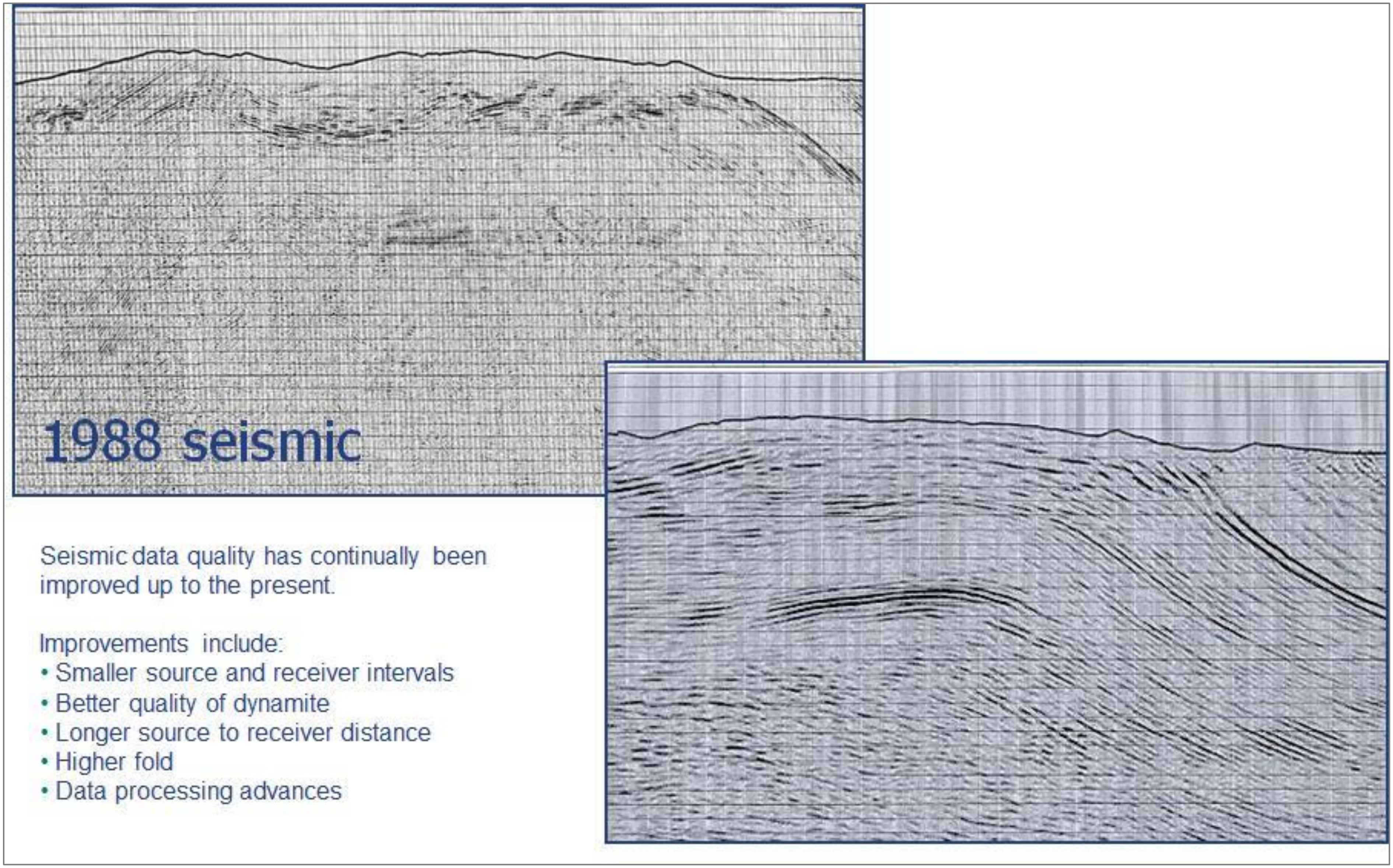


Figure 2. Example highlands shot record (AGC applied).



Seismic data quality has continually been improved up to the present.

Improvements include:

- Smaller source and receiver intervals
- Better quality of dynamite
- Longer source to receiver distance
- Higher fold
- Data processing advances

Figure 3. Data comparison between 1998 and 2005 acquired data.

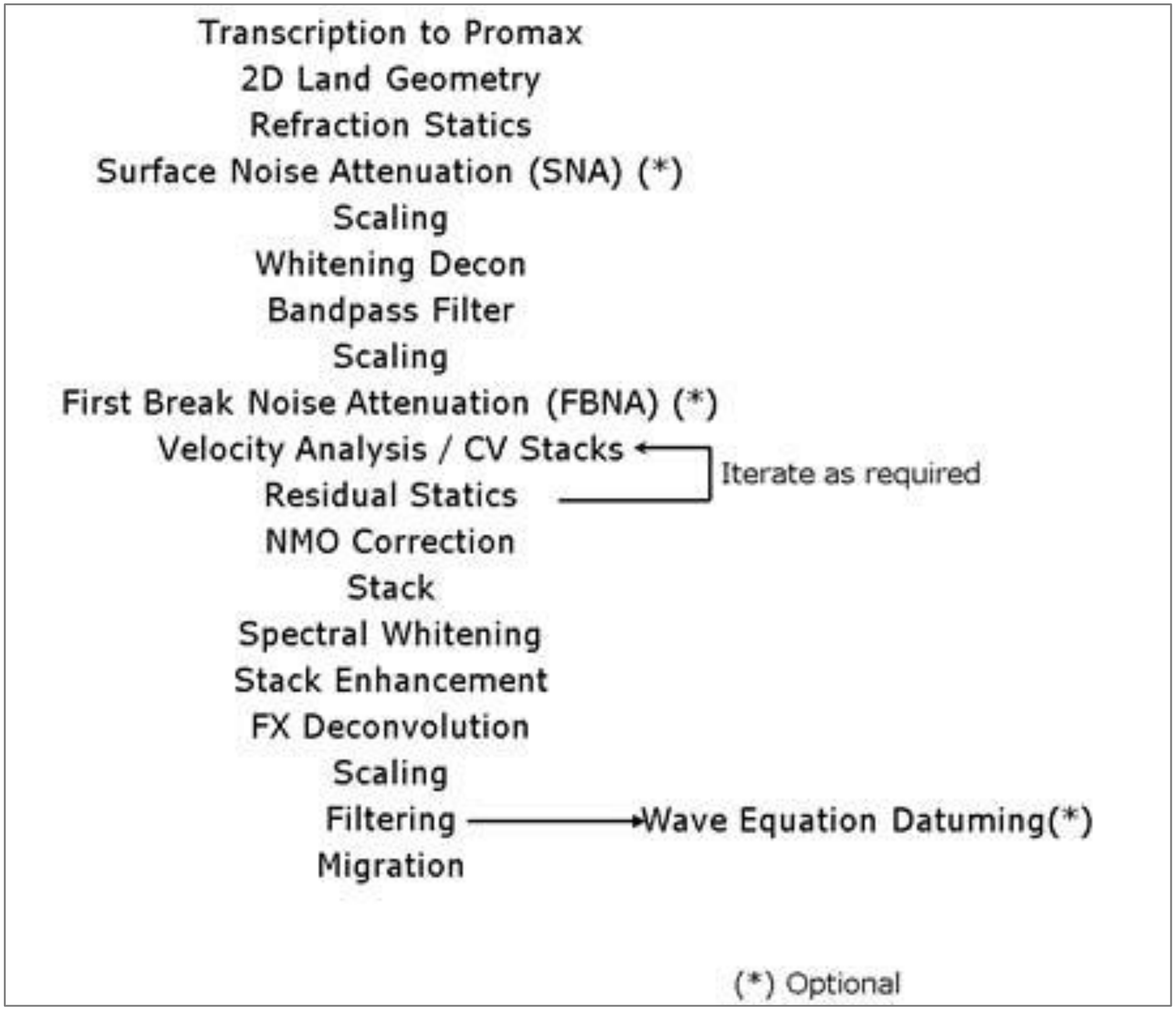


Figure 4. Processing sequence using poststack imaging.

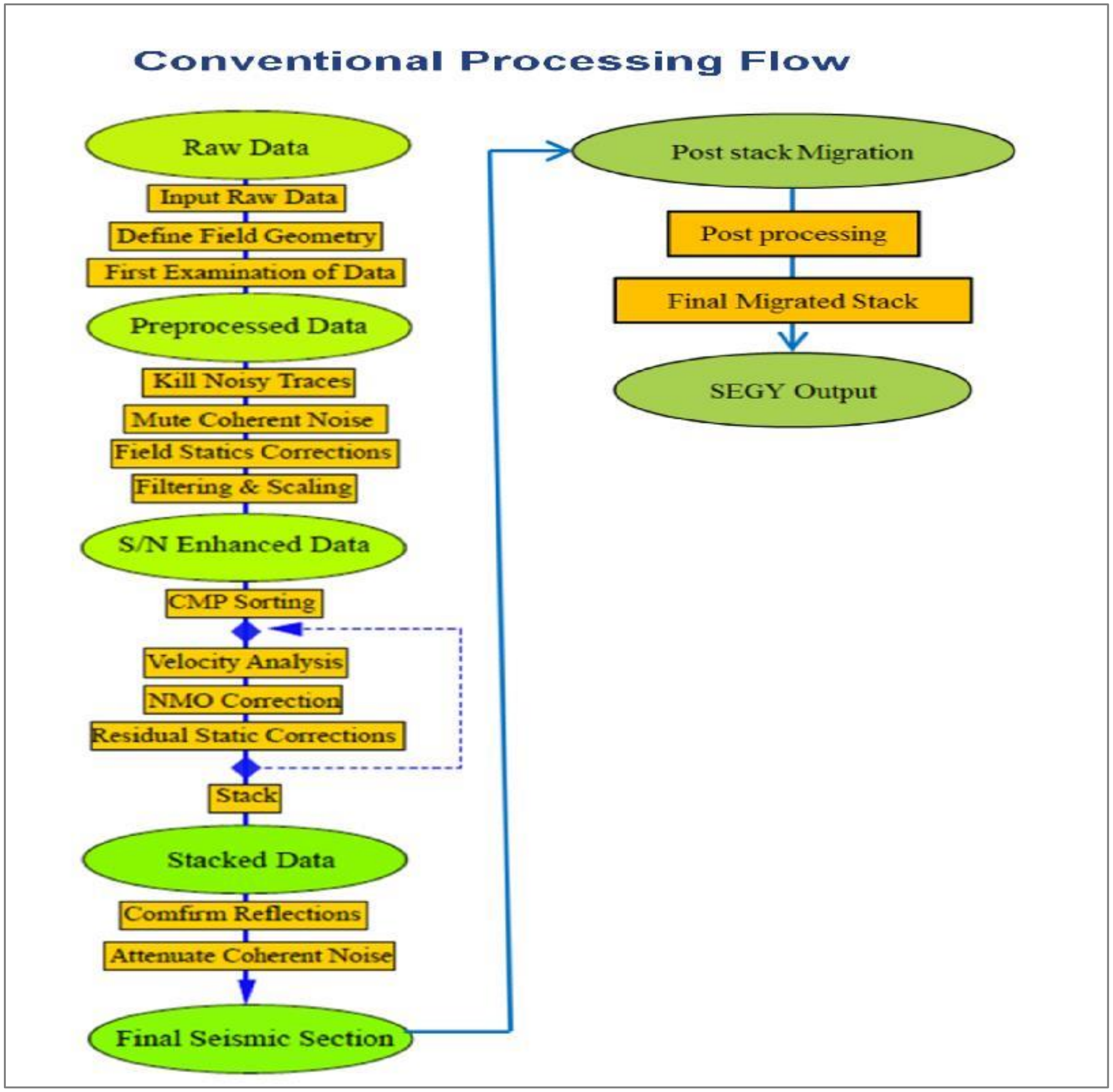


Figure 5. PSTM conventional processing flow.

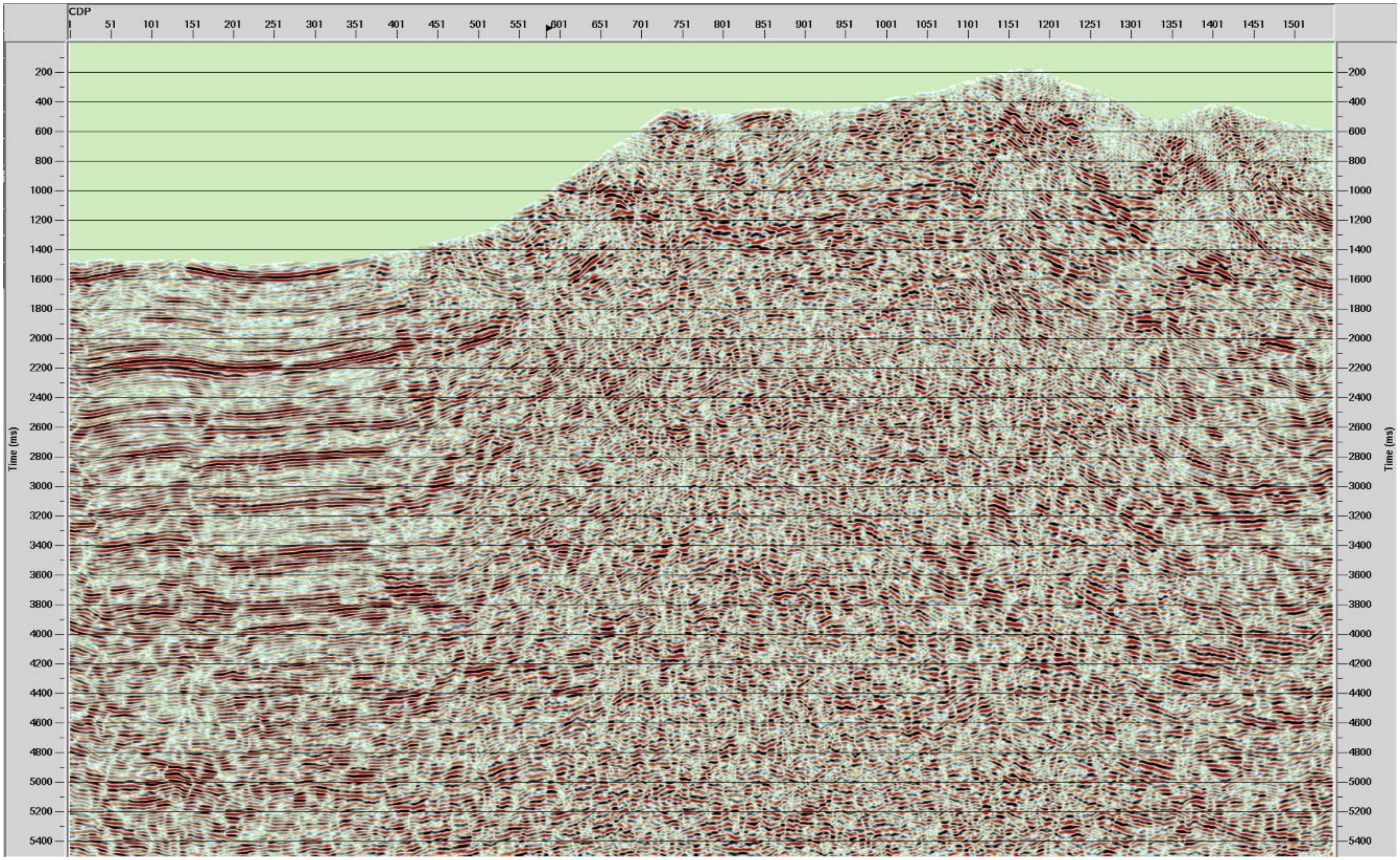


Figure 6. PSTM stack using conventional processing flow.

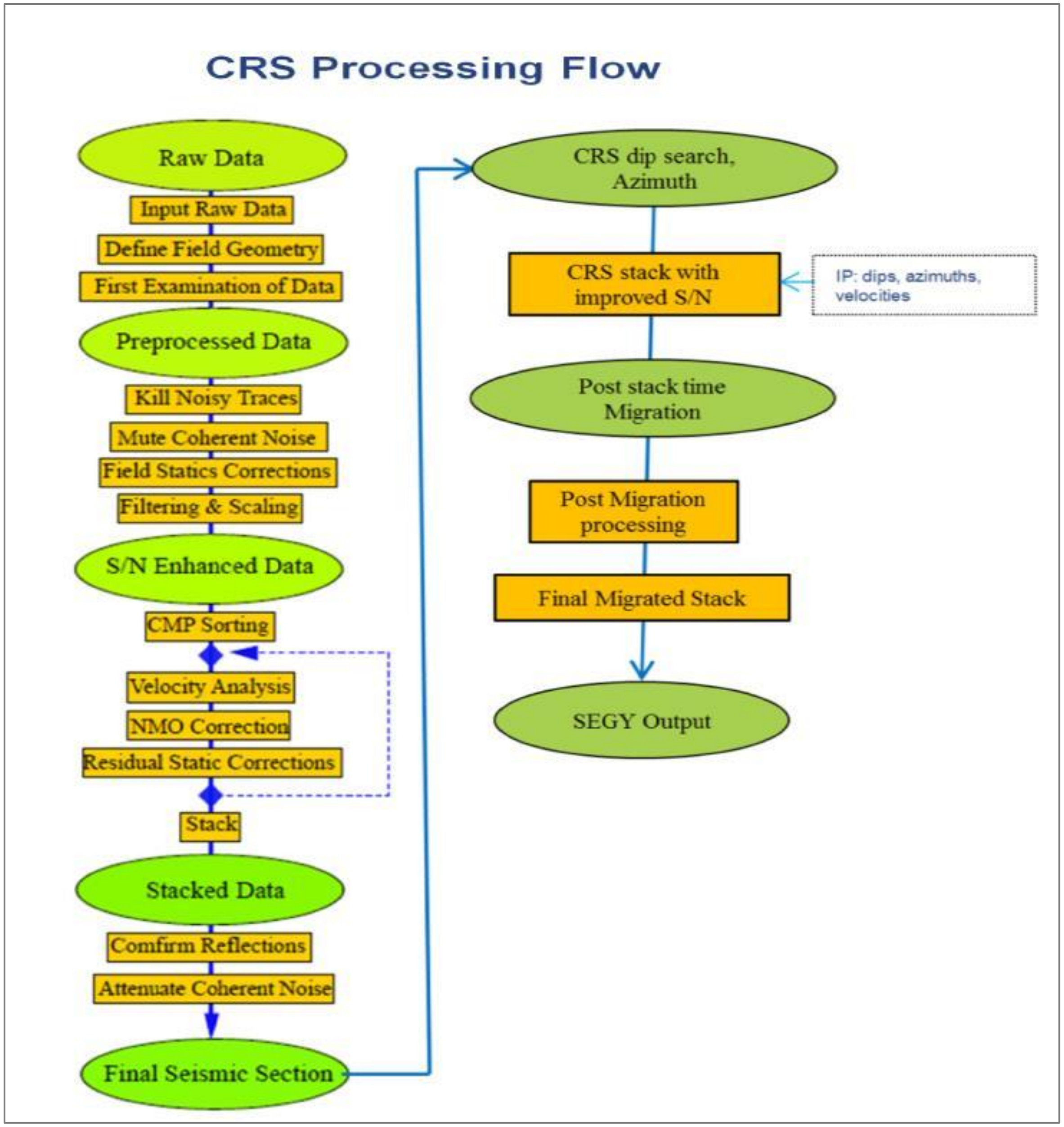


Figure 7. Poststack CRS processing flow.

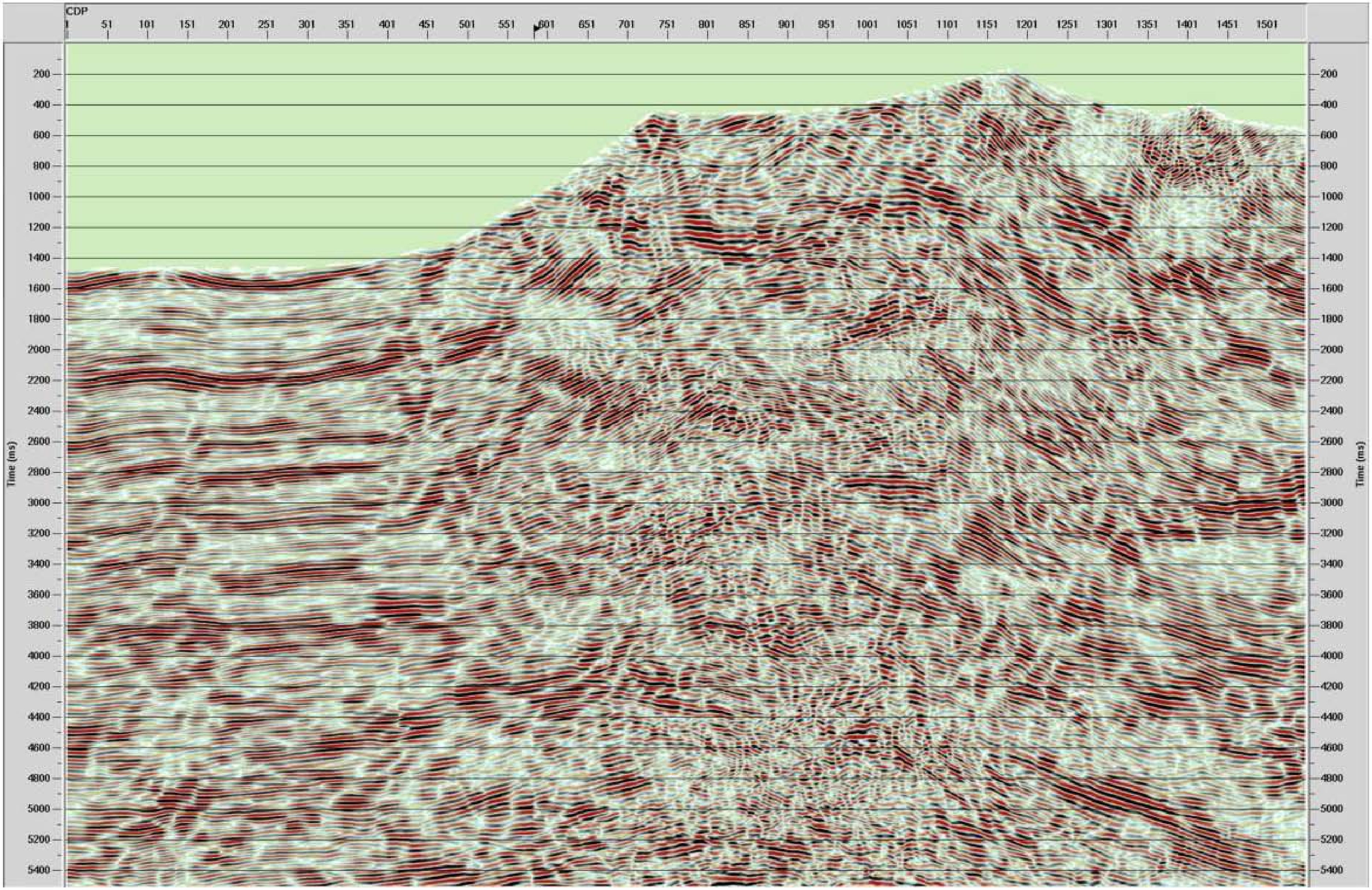


Figure 8. PSTM stack using poststack CRS processing flow.

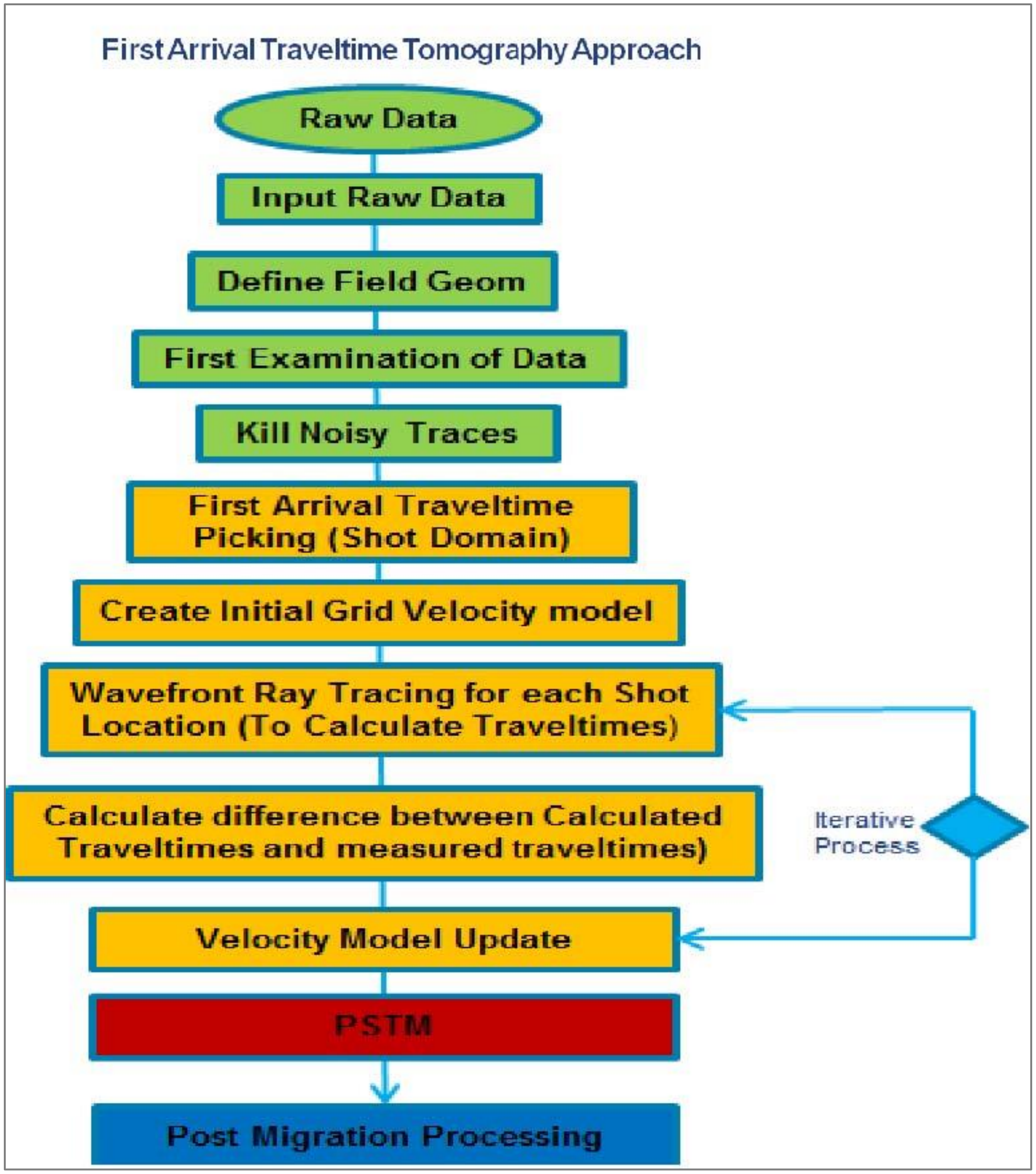


Figure 9. PSTM First Arrival Travel-time Tomography (FAT) processing flow.

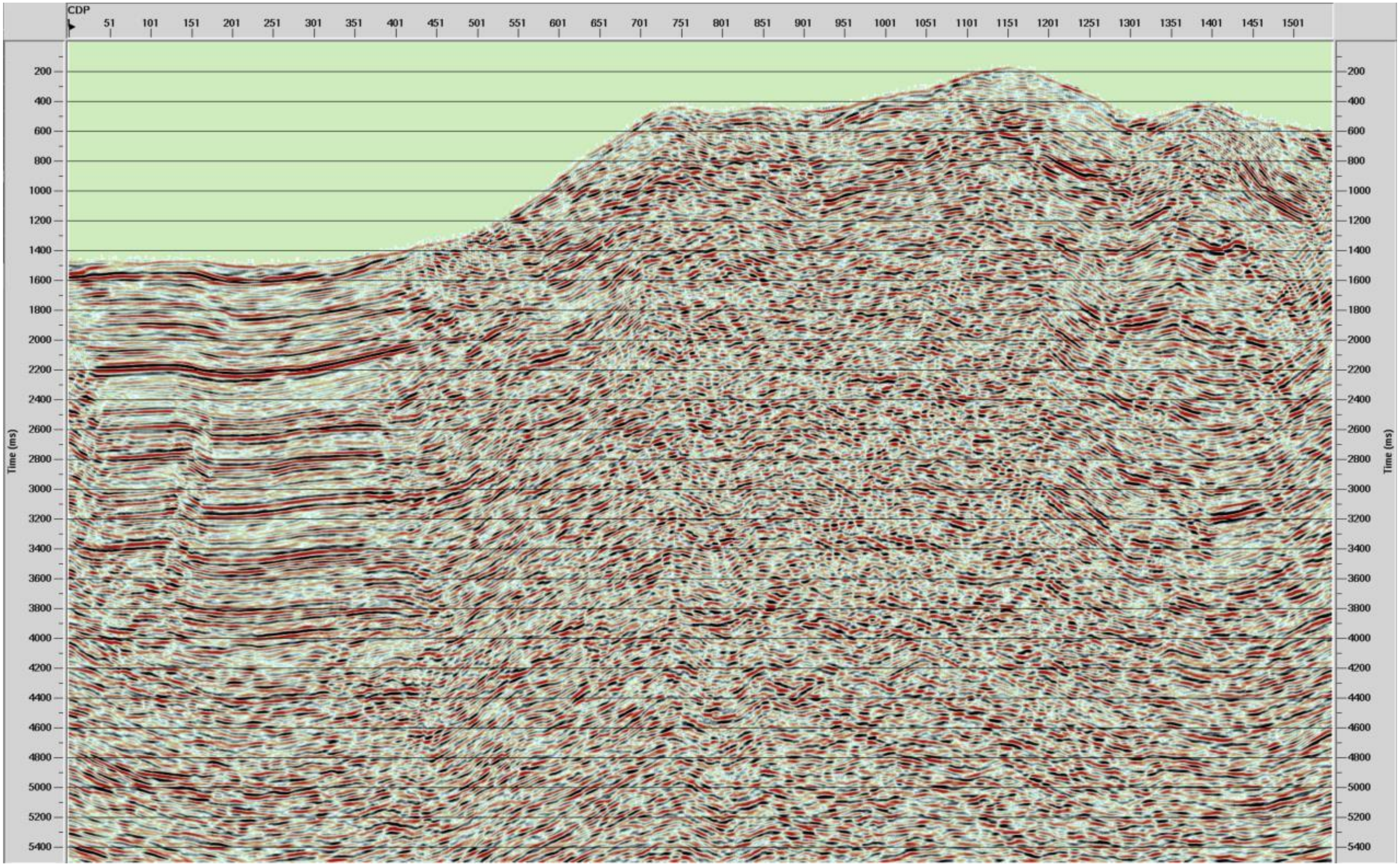


Figure 10. PSTM stack using First Arrival Travel-time Tomography processing flow.